

Letters to the Editor.

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The Acoustics of Enclosed Spaces.

THE acoustics of enclosed spaces intended to hold large audiences is now receiving attention, and it is recognised that good conditions for distinct hearing can be obtained only by eliminating the reverberation due to reflection from the walls. Owing to the high velocity of the transmission of sound in nearly all solid bodies, the angle at which total reflection begins is small; for oak wood it is about 6° , and for glass as low as 3° . Unless the wave-front is therefore very nearly parallel to a wall it cannot penetrate and is sent back into the room. The simple and partially effective method of deadening the reverberation by covering the walls with a highly porous material, or woven stuffs, is difficult to apply in large spaces, and a more hopeful solution of the problem seems to me to lie in the discovery of a substance that can be used for the exterior lining of walls and has a velocity of transmission not far different from that in air.

Unfortunately our knowledge of the velocity of sound in different materials is very scanty. I am not aware that the acoustical properties of the substances most commonly used in buildings, such as stones, brick, and mortar or plaster of Paris, have ever been examined. My suggestion is to look for a suitable material which is transparent to sound and can be backed by highly porous matter which will absorb the transmitted vibration. If necessary, a series of alternate layers may be introduced. In referring to the tables of Landolt-Börnstein I find that the substance which has a velocity of transmission for sound nearest to that of air is cork. This might be taken as a starting point for further investigation, but there are great gaps and inconsistencies in the tables.

It is to be remarked that at nearly normal incidence, so long as no total reflection takes place, the posterior surface of the wall diminishes very considerably the intensity of the reflected sound. This is illustrated by the analogous problem in the theory of light. Applying the relevant equations (A. Schuster, "Optics," p. 71) to normal incidence we find for the reciprocal of the intensity of a wave transmitted through a wall: $1 + \pi^2(1 - \mu^2)^2 e^2 / \lambda^2$, where e is the thickness of the wall, λ the wave-length in air, and μ the refractive index. It is here assumed that the thickness of the wall is small compared with the wave-length measured inside the wall, which will nearly always be the case. For wood the refractive index is about $\cdot 1$, and for stone it will probably be of the same order of magnitude. Applying the equations and assuming the wave-length to be 250 cm. in air, representing a frequency of 130, we find that a wall one metre thick would transmit 86 per cent. of the incident sound at normal incidence, and this would be increased to 98.5 per cent. if the thickness be reduced to 10 cm. Apart from absorption, it is to be expected that stone walls are fairly transparent to sound falling normally upon them. But, as has been said at the beginning, sound incident at angles slightly inclined to the normal is totally reflected.

Some interest attaches to the cognate problem of avoiding the transmission of sound from one room to another. I am not referring to the construction of sound-proof spaces of comparatively small dimen-

sions, such as telephone boxes, where the use of absorbing materials is permissible. But we are all familiar with rooms, more especially in hotels, where everything that is said in one room can be overheard next door. This is generally ascribed to the thinness of the walls. Apart from absorption, which is not likely to be very appreciable in a homogeneous material, no large diminution of the intensity of the transmitted sound should be expected from a moderate increase in the thickness of the walls. The above example shows what may be expected from theory. When we deal with bricks and mortar, or lath and plaster, the want of homogeneity may cause a considerable amount of scattering, and this would help in making the increased thickness more effective.

Unless my information as to our present knowledge is insufficient, it would appear that experimental investigation of the acoustical properties of materials, with regard to absorption, scattering, and the rate of transmission, are much needed at the present time. Such investigations may also have a theoretical interest, as they would include experiments on sheets, the thickness of which bears a much smaller ratio to the wave-length than we are accustomed to deal with in optics.

ARTHUR SCHUSTER.

Some Spectrum Lines of Neutral Helium derived theoretically.

IT is well known that, owing to the prohibitive nature of the general problem of three (or more) bodies, Bohr's quantum theory has proved so far to be unable to account for any spectrum lines but those forming a series of the simple Balmerian type, *i.e.*

$$\nu = \kappa^2 N \left(\frac{1}{n^2} - \frac{1}{m^2} \right),$$

where N is the familiar Rydberg constant given by $2\pi^2 me^4 / ch^3$, and κ the number of unit charges contained in the nucleus, or the atomic number. Apart from X-ray spectra of the higher atoms, for which κ is replaced empirically by a smaller and not necessarily a whole number (Moseley, Sommerfeld), and where the requirements of precision are not high, this simple type of formula covers, as a matter of fact, only the spectra of atomic hydrogen ($\kappa = 1$) and of ionised helium ($\kappa = 2$), which, having been deprived of one of its electrons, presents again the same problem of two bodies as the hydrogen atom. Accordingly, the known spectrum series of He^+ , the ultraviolet Lyman series, the principal or Fowler's series, and the Pickering series, are all of the simple Balmer type, with $n = 2, 3, 4$ respectively.

The neutral helium atom, however, with its two electrons, emits an entirely different spectrum consisting in all of more than a hundred lines (Prof. Fowler's latest report contains, pp. 93-94, a list of 105 lines), some apparently "stray" lines, others arrayed empirically into series strongly deviating from the Balmer type, but all alike baffling modern theoretical spectroscopists. In fact, not a single one of these one hundred or so observed lines has, to my knowledge, been accounted for theoretically, the mere desire of attempting this being paralysed by the insuperable difficulty of the three-bodies problem. This is particularly so in the case of lithium ($\kappa = 3$) and the higher atoms.

Now, it has occurred to me that, in the absence of a general solution (in finite form, of course), it may be worth while to try some special solution of that classical problem.

At first a sub-case of Lagrange's famous solution of 1772 suggested itself, namely, the collinear type of motions, in which the three bodies, in our case

the nucleus and the two electrons, are always collinear with each other, the latter describing two equal and oppositely situated ellipses around the former. But the corresponding spectrum formula, which is again

of the simple Balmer type, namely, $\nu = \frac{49N}{8} \left(\frac{1}{n^2} - \frac{1}{m^2} \right)$,

proved to be entirely useless, as (to judge from one's numerous trials extended up to $n=8$) it does not cover, even within $1.5\text{\AA}$, a single observed line of He. This tends to show that such extremely special (collinear) states of motion, or at least passages between them, do not occur within the He-atoms, or if they do, then only so sporadically as to give no light of observable intensity.

What next suggested itself was the apparently trivial class of motions in which the *mutual perturbation of the two electrons is negligible*. Though approximate only, this class of solutions, being much broader than that of the collinear motions, would seem more likely to cover some actual spectrum lines. In fact, the very first trials gave encouraging results, as will be shown presently.

The energy of the system being for such states of motion equal to the sum of the energies due to the nucleus and each of the electrons taken separately, the corresponding spectrum formula for neutral helium is, obviously,

$$\nu = 4N \left(\frac{1}{n_1^2} + \frac{1}{n_2^2} - \frac{1}{m_1^2} - \frac{1}{m_2^2} \right),$$

or $\nu = \nu_1 + \nu_2$, where ν_1 and ν_2 are any two frequencies belonging to ionised helium, and thus represents a "combination principle" of a new kind. The resulting line of He, due to the passage of the two electrons from stationary orbits determined by m_1, m_2 to a pair of orbits determined by n_1, n_2 , may conveniently be denoted by $\left(\frac{m_1 \cdot m_2}{n_1 \cdot n_2} \right)$.

This simple spectrum formula, the sum of two Balmerian ones, has yielded so far ten or eleven remarkably well-fitting lines, of which it will be enough to quote here a few.

Thus, to start with lines of the type $\left(\frac{m_1 \cdot m_2}{4 \cdot 4} \right)$, i.e. derivable from the Pickering series $\left(\frac{m}{4} \right)$ of He^+ , we have the frequencies (ν_1, ν_2)

$$\left(\frac{5}{4} \right) \dots 9875.1,$$

$$\left(\frac{14}{4} \right) \dots 25191.8,$$

the sum of which gives for the frequency of the theoretical line $\left(\frac{5 \cdot 14}{4 \cdot 4} \right)$

$$\nu = 35067.$$

This agrees very closely with the nearest observed line at $\lambda(\text{air}) 2851$ or $\nu = 35065$, which is tabulated among the combination lines of neutral helium (Fowler, p. 94). Similarly the members $\left(\frac{5}{4} \right)$ and $\left(\frac{20}{4} \right)$

of the Pickering series of He^+ give $\left(\frac{5 \cdot 20}{4 \cdot 4} \right)$ with the frequency

$$\nu = 9875.1 + 26333.6 = 36209,$$

which is in striking coincidence with the observed He-line at $\lambda = 2761$ or $\nu = 36208$.

In these examples both ν_1 and ν_2 are frequencies actually observed in He^+ . But not less interesting are lines of the type $\left(\frac{m_1 \cdot m_2}{4 \cdot 5} \right)$, i.e. combinations of Pickering lines with those of a purely theoretical

He^+ series $\nu = 4N \left(\frac{1}{5^2} - \frac{1}{m^2} \right)$, and yet covering some observed lines of neutral helium very closely. Thus, we have (with $N = 109723$) :—

$$\left(\frac{6 \cdot 9}{4 \cdot 5} \right), \nu = 27377, \lambda = 3651.8,$$

$$\left(\frac{6 \cdot 17}{4 \cdot 5} \right), \nu = 31276, \lambda = 3196.4,$$

$$\left(\frac{6 \cdot 19}{4 \cdot 5} \right), \nu = 31579, \lambda = 3165.7,$$

the nearest observed lines of neutral helium being $\lambda 3652.0, 3196.7$, and 3166 respectively.

Finally, an example in which both of the combined frequencies are purely theoretical is

$$\left(\frac{6 \cdot 28}{5 \cdot 5} \right), \nu = 22360, \lambda = 4471.00,$$

with the nearest observed He-line at $\lambda = 4471.48$, tabulated (*l.c.*, p. 93) among the diffuse doublets.

Other examples of well-fitting lines and some further details are being given in a paper on this subject to appear in the September issue of the *Astrophysical Journal*.

Similarly one could try to cover some Li-lines by three pairs of terms, i.e. by $\nu = 9N \left(\frac{1}{n_1^2} + \frac{1}{n_2^2} + \frac{1}{n_3^2} - \frac{1}{m_1^2} - \frac{1}{m_2^2} - \frac{1}{m_3^2} \right)$, and some spectrum lines of the higher atoms by four and more pairs of terms. But since, with increasing number of independent term-pairs, even a thorough agreement would appear more and more likely as the work of chance, it does not seem worth while to push the procedure much beyond lithium. For the latter element I have thus far found (with $N = 109730$) eight well-fitting lines, of which the most interesting lines are

$$\left(\frac{5 \cdot 14 \cdot 18}{4 \cdot 13 \cdot 17} \right), \nu = 23394.4 \text{ and } \left(\frac{5 \cdot 12 \cdot 21}{4 \cdot 10 \cdot 18} \right), \nu = 26046.6,$$

which are remarkably close to the lithium lines observed at $\nu = 23394.7$ and 26046.9 . But by far more interesting seem, for the present at least, the coincidences obtained for neutral helium. These would seem to justify the conclusion that there is a good deal of independence between its electrons.

LUDWIK SILBERSTEIN.

July 18.

In my letter of July 18 I considered the formula :

$$\nu = 4N \left[\frac{1}{n_1^2} + \frac{1}{n_2^2} - \frac{1}{m_1^2} - \frac{1}{m_2^2} \right],$$

constructed as if the two electrons did not influence each other at all, and I mentioned that this spectrum formula had yielded ten or eleven well-fitting lines, of which six were actually quoted, the remaining lines being given in the full paper appearing in the *Astrophysical Journal*.

I now write to say that, to my own surprise, the same formula has since covered more than thirty further lines of neutral helium, and that when the whole ground is swept (by means of an auxiliary arithmetical table), almost the whole observed spectrum of helium is likely to be thus represented. While a complete list will be found in the paper referred to, some of these further lines may be quoted here so as to give an idea of the closeness of the agreement. Using the short symbol $\left(\frac{m_1 \cdot m_2}{n_1 \cdot n_2} \right)$ as already explained, we have, to five figures :—

Line.	$\nu_{calc.}$	$\nu_{obs.}$	Line.	$\nu_{calc.}$	$\nu_{obs.}$
$\left(\frac{9.24}{6.7}\right)$	14968	14970	$\left(\frac{22.24}{5.7}\right)$	24843.9	24843.96
$\left(\frac{9.15}{6.6}\right)$	17014.0	17014.3	$\left(\frac{7.19}{5.5}\right)$	24939	24935
$\left(\frac{6.10}{4.7}\right)$	19807	19805	$\left(\frac{7.21}{5.5}\right)$	25159	25157
$\left(\frac{14.14}{5.8}\right)$	19935	19932	$\left(\frac{11.22}{5.6}\right)$	25213	25215
$\left(\frac{7.11}{5.5}\right)$	22527	22529	$\left(\frac{9.18}{4.8}\right)$	25822	25820
$\left(\frac{7.18}{4.8}\right)$	23977	23980	$\left(\frac{15.15}{5.6}\right)$	25846	25849
$\left(\frac{10.20}{5.6}\right)$	24261	24260	$\left(\frac{13.20}{5.6}\right)$	26053	26047

The ν -region beyond 26047 has thus far not been swept systematically. When this is done, I have but little doubt that ninety or more of the one hundred and five lines of helium will be accounted for. In these circumstances one would feel justified in asserting that the absence of mutual repulsion between the electrons is not (as I first thought) an exception but rather the rule. A simple estimate will show that if the usual Coulomb repulsion law were valid in any of the considered stationary states, the mutual energy of the electrons would contribute several thousand units to ν . Since it is hard to explain away so many coincidences as due to chance, we are driven to the belief that the electrons within the atom do not repel each other even with a small fraction of the force usually attributed to them. In other words, the field of force of a bound electron seems to be entirely engaged by the nucleus, at least in the case of helium and probably of lithium, but possibly also in that of the higher atoms. LUDWIK SILBERSTEIN.

129 Seneca Parkway, Rochester, New York,
July 26.

The Primitive Crust of the Earth.

IN reference to the letter of Dr. Harold Jeffreys (NATURE, July 29, 1922), I wish at once to say that nothing in my letter published on July 8 was intended to express my adhesion or non-adhesion to those who support the planetesimal hypothesis. Even if we think that the earth originated in a rain and concentration of solid planetesimals, we may, with Prof. R. A. Daly, regard its complete fusion at a later stage as a very probable event. At some time or other, the earth may well have possessed a crust consolidated from "igneous" fusion. Prof. J. Joly now suggests to us, with his unflinching brilliance of outlook, the recurrence of such a crust after successive meltings of the globe. What I have urged, however, is that the oldest rocks traceable by geologists must not be regarded as a record of a primitive crust. They are sediments, invaded again and again by igneous matter from below. We cannot conclude from our Archæan schists, which are so often converted into composite gneiss, that there was ever a crust formed of crystalline rocks about the globe. The "extent of the crust accessible to geologists" is, of course, much more than the film 2.5 km. thick stated by Dr. Harold Jeffreys. Owing to the great movements that bring up antique masses from the depths, rocks that consolidated finally under several miles of sediments now form a large part of the surface. But so far no planetesimal sediment has come to light, although matter of the mineral composition demanded by the hypothesis is associated with many igneous upwellings.

In support of the concluding remarks of Dr. Harold Jeffreys, attention may be directed to "A Critical Review of Chamberlain's Groundwork for the Study of Megadiastrophism," by W. F. Jones, published in the *American Journal of Science* for June of the present year. GRENVILLE A. J. COLE.

Carrickmines, Co. Dublin, July 29, 1922.

Peculiarities of the Electric Discharge in Oxygen.

SEVERAL years ago I described (*Phil. Mag.*, April 1908) a discontinuity in the electric discharge in oxygen at pressures near to 0.8 mm. Namely, when a current (0.0025 amp.) was passed in a discharge tube (diam. 2.4 cm.), the electric force in the positive column suddenly changed on slightly lowering the pressure from about 11 volts per cm. to about 20, an effect which could be reversed by raising the pressure.

Some experiments which I have made recently, with the assistance of Mr. E. P. Cardew, have shown that at pressures in the same neighbourhood, with a fixed circuit (battery and resistance), the discharge is not uniquely determined, but can be one or the other of two distinct types, distinguished by a remarkable difference in the values of the electric force within the positive column, one of these values being about twice the other. The magnitude of the current with the higher electric force in its positive column is less than the other, since the potential difference of the electrodes is greater in its case; but the currents tend to equality when the electrodes are so near that the positive column tends to disappear. The two discharges differ only slightly in appearance: the positive column of the smaller one with the higher electric force being somewhat shorter and a trifle paler than the other—both being without striæ in general.

To give an example. With a battery of 990 volts and external resistance 363,000 ohms, electrodes 21.8 cm. apart in a tube of 27 mm. diameter, and pressure 0.75 mm., the currents observed were 1.19 and 0.883 milliamperes; their positive columns were nearly 15 and 14 cm. long, and the electric force within them about 9 and 18.5 volts per cm. respectively. In this and in many other cases, by means of a certain arrangement, the discharge could be made to change from one form to the other without stopping the current or altering the circuit.

The region of pressures within which alternative currents have been so far observed are from 0.64 to 0.91 mm. The two types of discharge differ in stability according to the pressure and the magnitude of the currents, so that the discharge tends to assume one type rather than the other. But the one having the high electric force in the positive column is much more definite and invariable than the other for a given pressure, being in this respect similar to discharges in other gases, so that that electric force can be determined with much more precision, and is in fact nearly the same as in hydrogen.

Since these effects hold good for a large range of current, it is obviously possible, by adjusting the external circuit, to make two discharges of the same arbitrary magnitude (of the necessary order) pass through oxygen, between electrodes at a given distance apart, at any given pressure within the range in question, one of which will have the high electric force in its positive column and the other the low.

P. J. KIRKBY.

Saham Toney Rectory, Watton, Norfolk,
July 26.